Biological Forum – An International Journal 14(1): 908-913(2022)

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Development of Geomorphological Instantaneous Unit Hydrograph (GIUH) Model for a Watershed of Damodar Valley Corporation, Hazaribagh (Jharkhand), India

Safi Hassan, R. Suresh and S.K. Nirala*
Department of Soil & Water Engineering, College of Agricultural Engineering
Rajendra Prasad Central Agricultural University Pusa, Samastipur, (Bihar), India.

(Corresponding author: S.K. Nirala)*
(Received 23 October 2021, Accepted 07 January, 2022)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: A GIUH model was developed using Nash (1959) and Rodriguez-Itrube (1982) methods to compute peak discharge (q_{peak}) and time to peak (t_{peak}). The model was calibrated and validated for five storm events, *i.e.* June 24 -25 (1992), October 12 -13 (1993), November 2-3(1993), June 28 (1994) and August 6 (1996) by comparing their ordinates with the ordinates of IUH The GIUH was tested with APE of the ordinate of peak discharge. On comparison, it was found that, most of the GIUH models over estimated the runoff at initial stage, while underestimated at the latter stage in comparison to the IUHs, which was mainly due to consideration of constant value of Φ-index, for computation of effective rainfall. The absolute prediction errors (A.P.E.) were computed to be 5.97, 18.09, 23.32, 9.64 and 7.52% of the ordinates of peak discharge for the storm events of June 24 -25 (1992), October 12 -13 (1993), November 2 -3 (1993), June 28 (1994) and August 6 (1996), respectively.

Keywords: Geomorphological characteristics, watershed, instantaneous unit hydrograph, geomorphological instantaneous unit hydrograph.

INTRODUCTION

Land is non-renewable resource which support all primary production function for food, fodder etc. The land behavior on its production system is largely affected by rainfall and its associated factors imposing various problems. The problems may be of soil loss, flood generation and land degradation. It has been found that in India the occurrence of soil loss each year is in the order of 5000 million tones, out of 2000 million tones is transported by river into storage structure or into sea. The rainfall - runoff relationship is an important tool for approximation of runoff likely to be generated by the rainfall from the watershed, which may be useful for better planning of water resource system and management of the watershed, as well. Many such models are in use in hydrology (Rodrìguez-Iturbe and Valdes, 1979; Rodrìguez-Itrube *et al.*, 1982; Singh 1983; Subramanyan & Kumar 1990; Troutman & Karlinger 1985; Bhaskaran *et al*., (1997). However, they require a long-term database on the rainfall and runoff for the watershed. Due to paucity of runoff data in many catchments such models are useful especially in un-gauged catchments. However, the geomorphological technique to synthesize the unit hydrograph on the basis of morphological characteristics of watershed, added a new dimension to the field of hydrologic simulation (Rodrìguez-Itrube *et al.*, 1982). On this concept, several attempts have been made to relate the parameters of unit hydrograph with the geomorphological characteristics of the watershed, which in turn to the development of geomorphological instantaneous unit hydrograph (GIUH) for the un-gauged watershed. Zhao *et al.* (1995) derived unit hydrograph by ridge least-square (LS) method. In this method unit hydrograph is obtained by minimizing the mean squared error (MSE) of the estimated init hydrograph obtained by the ridge LS method has a better predicative capacity than the one derived by the ordinary LS method. Franchini *et al.* (1996) analyzed the dynamic component of the geomorphological instantaneous unit hydrograph (GIUH) and draw a contrast between the geomorphologic and hydraulic component of GIUH and those of a width function based IUH. Kumar (1999) applied the Nash model based concept of instantaneous unit hydrograph to evaluate hydrograph parameter of hilly watershed of lower Bhawan catchment. The significance correlation (r=0.96) between Nash parameter product (nK) and rainfall excess of storm event (R_e) have shown that peak discharge (q_p) nd time to peak (t_p) varied by 18 per cent and 0.13 hr, respectively as compared to observed peak discharge and time to peak.

With aforesaid views, in present study the geomorphological instantaneous unit hydrograph model was developed, using a popular approach in new catchment, *i.e*., Kahuwatri sub-catchment of Damodar Valley Corporation, Hazaribagh, Jharkhand (India).

MATERIALS AND METHODS

A. Development of I.U.H.

Data Collection: The requisite database on rainfall and runoff for five storm events, i.e. June 24-25 (1992), October 12-13 (1993), November 2-3 (1993), June 28 (1994) and August 6 (1996); and topographic map of the watershed were collected from the department of soil & water conservation, located at Damodar Valley Corporation, Hazaribagh (Jharkhand). The other input data for development of geomorphological instantaneous unit hydrograph were also borrowed from the available literatures.

The Nash model (Nash, 1959) was used to derive the instantaneous unit hydrograph for different storm events, which consists of determining the Nash model parameters, *i.e.* shape parameter (n) and scale parameter (K) for given storm events. The depth of direct runoff is computed by using the standard method given by Chow (1964). The Nash parameters (n and K) were determined by the method suggested by Nash (1957). Finally, the ordinates of storm instantaneous unit hydrograph were computed by using the following formula (Nash, 1959):

$$u(0,t) = \frac{1}{K\tau(n)}(t/k)^{n-1}e^{-t/k} \quad (1)$$

where, $u(t)$ is the ordinate of IUH (cm h^{-1}) at time *t* and symbol Γ is the gamma function. The computed ordinates of instantaneous unit hydrograph (cm h^{-1}) were further converted in the unit of m^3/s, by multiplying the area of the watershed and a factor 2.78, i.e.

$$u(t)\ m^3/s = 2.78.A.\ u(t)\ cm\ h^{-1} \quad (2)$$

in which A is the area of watershed (sq km)

Development of G.I.U.H model

The ordinates of geomorphological instantaneous unit hydrograph (GIUH) were determined by using the eq. 1, in which the parameters n and K were computed (Rodrìguez-Itrube *et al.*, 1982) on the basis of geomorphological parameters of the watershed, i.e. bifurcation ratio (R_b), stream length ratio (R_l), stream area ratio (R_a) and the peak flow velocity (V_{max}). The computed ordinates (cm h^{-1}) of GIUH were also modified in the unit of m^3/s, by multiplying the area of the watershed and a factor 2.78.

Parameters of the G.I.U.H. The geomorphological parameters of watershed, i.e. bifurcation ratio (R_b), stream length ratio (R_l), stream area ratio (R_a) were evaluated by the method of Rodrìguez-Itrube, *et al.* (1982) which came to be 3.48, 1.549 and 3.66, respectively. The maximum flow velocity (V_{max}), peak discharge (q_p) and time to peak (t_p) were as determined by the following formulae (Sorman, 1995; Rodrìguez-Itrube, 1982):

$$V_{max} = \alpha_\Omega^{0.6} A_\Omega(i_c)0.4 \text{ for } t_e>t_c \quad (3)$$

$$V_{max} = \alpha_\Omega(t_c x i_c)^{2/3}(A_\Omega/L_\Omega)^{2/3} \text{ for } t_e<t_c \quad (4)$$

$$\text{in which, } \alpha_\Omega = S_\Omega^{0.5} / \eta b_\Omega^{2/3} \quad (5)$$

$$q_p = (1.31/L_\Omega).\ R_l 0.^{43}.V_{max} \quad (6)$$

$$t_p = (0.44\ L_\Omega/V_{max}).\ (R_b/R_a)^{0.55}.R_l^{0.38} \quad (7)$$

in which, t_e is the duration of excess rainfall (s); i_e is the intensity of excess rainfall (m/s); η is the Manning's roughness coefficient; t_c is the time of concentration (minute); S_Ω is the slope of main stream (m/m); L_Ω is the length of main stream (km), A_Ω is the area of watershed (m^2), b_Ω is the breadth of main stream (m) ; α_Ω is the kinematics wave parameter ($m^{-1/2}.\ s^{½}$).

The Nash parameters, *i.e.* n and K for GIUH were computed by using the following formulae (Subramanyan & Kumar, 1990; and Rosso, 1984):

$$\text{Shape parameter } (n) = 3.29\ (R_b/R_a)^{0.78}.R_l^{0.07}\ 0.70\ (R_a)^{0.48} \quad (8)$$

$$\text{Scale parameter } (K) = x(L_\Omega/V_{max})\ (R_b.\ R_l) \quad (9)$$

These relationships have been tested by Safi Hssan (2004), were found to be fit for the study watershed. The time of concentration (t_c) was determined by using the method suggested by Kirpich (1940) which came to be 149.79 minutes for the study watershed. The intensity of effective rainfall (i_e) was computed by dividing the depth of effective rainfall with its duration, which was obtained as 9.083, 9.41, 5.77, 1.44 and 4.83 m/s for the storm events of June 24 -25 (1992), October 12 -13 (1993), November 2 -3 (1993), June 28 (1994) and August 6(1996), respectively. TheManning's roughness coefficient(η) was taken as 0.04 (Chow, 1964) for the existing stream, bearing the features of steep sides slope, covered with trees, bushes and gravels or boulders lying at the bottom. The S_Ω was determined by dividing the difference of maximum and minimum elevations of the main stream, with its total length. The computed values of requisite parameters for determining the maximum flow velocity are shown in Table 1; and accordingly the maximum flow velocities for different storm events are given in Table 2.

Table 1: Requisite parameters for estimation of flow velocity.

Sr. No.	Parameter	Unit	Value
1.	Area of watershed (A_Ω)	m^2	27.93×10^6
2	Length of main stream (L_Ω)	m	1446.72
3.	Breadth of main stream (b_Ω)	m	19.00
4.	Slope of main stream (S_Ω)	m/m	1.75×10^{-4}
5.	Time of concentration (t_c)	min	149.77

Validation of GIUH. The validity of derived GIUHs was tested by two ways; in which one by comparing the ordinates of GIUHs and the observed; and second by determining the absolute prediction errors (APE) of their peak discharge ordinates. The following formula was used for computing the APE:

$$APE\ \% = \frac{\sum_{i=1}^{n}(O_i - P_i)}{\sum_{i=1}^{n}(O_i)} x\ 100 \quad (10)$$

in which, O_i and P_i are the observed and predicted ordinates of unit hydrographs, respectively. In this case, the ordinates of IUH were considered as the observed (O_i) and of GIUH as predicted (P_i) ordinates of the unit hydrograph.

RESULTS AND DISCUSSION

The computed values of Nash parameters, i.e. n and K for storm instantaneous unit hydrograph and geomorphological instantaneous unit hydrograph are shown in Table 2, which revealed that, in case of GIUH the value of shape parameter (n), which was determined on the basis of geomorphological characteristics of the watershed was found to be 3.26, while for IUH it was 1.12, 2.97, 2.82, 3.39 and 1.02, respectively for the storm events of June 24-25 (1992), October 12 -13 (1993), November 2 -3 (1993), June 28 (1994) and August 6 (1996). Comparatively**,** the value of n for GIUH was higher than the values of n for IUH, may be due to the effect of geomorphological characteristics of the watershed. The scale parameter (K) which represents the dynamic behavior of rainfall - runoff process in the watershed, was found to be different for different storm events for both the hydrographs, might be due to variations in the geomorphological characteristics of the watershed and peak flow velocity. Overall, for most of the storm events, the values of K (1.22, 0.34, 0.85, 0.74 and 1.43) for IUH were found to be less as compared to the GIUH (0.45, 0.29, 0.62, 0.74 and 0.70). On the contrast, the products of n and K (n. K) which represent the lag time of watershed were found to be at par , for both the unit hydrographs, i.e.1.25, 1.01, 2.40, 2.50 and 1.45 in case of GIUH and 1.47, 0.95, 2.38, 2.48 and 2.28 in case of IUH, respectively for the storm events of June 24 -25 (1992), October 12 -13 (1993), November 2 -3 (1993), June 28 (1994) and August 6 (1996), resulting into the same time to peak of the GIUH and IUH (Table 3) for most of the storms, *i.e*. Oct 12-13 (1993), Nov 2-3(1993) and Jan 28 (1994).

Table 2: Computed values of shape factor (n) and scale parameter (K) for IUH and GIUH.

Sr. No.	Storm event	V_{max} (m/s)	Shape parameter (n)		Scale parameter (K)	
			IUH	GIUH	IUH	GIUH
1.	June24-25 (1992)	0.78	1.12	3.26	1.22	0.45
2.	Oct 12-13 (1993)	1.20	2.97	3.26	0.34	0.29
3.	Nov 2-3 (1993)	0.55	2.82	3.26	0.85	0.62
4.	Jun 28 (1994)	0.41	3.39	3.26	0.74	0.74
5.	Aug 6 (1996)	0.50	1.02	3.26	1.43	0.70

Table 3: Computed n.k of IUH and GIUH for different storm events.

Storm event	n. k		Time to peak, hour	
	IUH	GIUH	IUH	GIUH
June24-25 (1992)	1.25	1.47	0.50	1.00
Oct 12-13 (1993)	1.01	0.95	0.50	0.50
Nov 2-3 (1993)	2.40	2.38	1.50	1.50
Jun 28 (1994)	2.50	2.48	2.00	2.00
Aug 6 (1996)	1.45	2.28	1.00	0.50

The computed ordinates of IUH and GIUH for different storm events are given in Tables 4 and 5, respectively, which plotting are shown in Fig. 1 and 2, respectively. On comparison, it was found that at the initial stage, the GIUH overestimated the runoff while at later stage; they underestimated the runoff for most of the storm events. It may be due to consideration of constant value of Φ- index for determining the depth of effective rainfall. The constant Φ-index resulted a lower infiltration rate (*i.e*. initial loss) in the beginning; and higher at the latter stage of runoff formation, as compared to the actual infiltration rate. Such variations between the runoff of GIUH and SIUH have also been reported by Ashokan (1981); Bhashkar *et al*. (1997); Kumar (1999).

The validity of GIUHs was evaluated over IUHs on the basis of comparison between their ordinates; and absolute prediction error (APE) of q_{peak}. As shown in Fig. 1 and 2, it was found that in most of the storm events, the ordinates of SIUH and GIUH are close to each other, which reveals the validity of developed GIUHs. The computed values of absolute predictionerror (APE) at peak discharge were found to be 5.97, 18.09, 23.32, 9.64 and 7.52.For the storm events of June 24-25(1992), October 12-13(1993), November 2-3(1993), June 28 (1994) and August 6 (1996), respectively (Table 6). Similar reporting have also been made by Bhashkar, *et al.* (1997); Ashokan (1981); Kumar (1999) with the claim of validity of geomorphological instantaneous unit hydrograph.

Thus, it may be concluded that, the developed geomorphological instantaneous unit hydrograph, based on the geomorphological characteristics of the study watershed (i.e. Kahuwatri watershed), located in the Damodar Valley Corporation, Hazaribagh (Jharkhand) is well suitable for prediction of direct runoff. It can be used as a tool for predicting the runoff, for other watersheds, provided that they fall in the same meteorological region; with identical physiographical features. However, for its more versacity, the developed instantaneous unit hydrographs should also be tested for other watersheds.

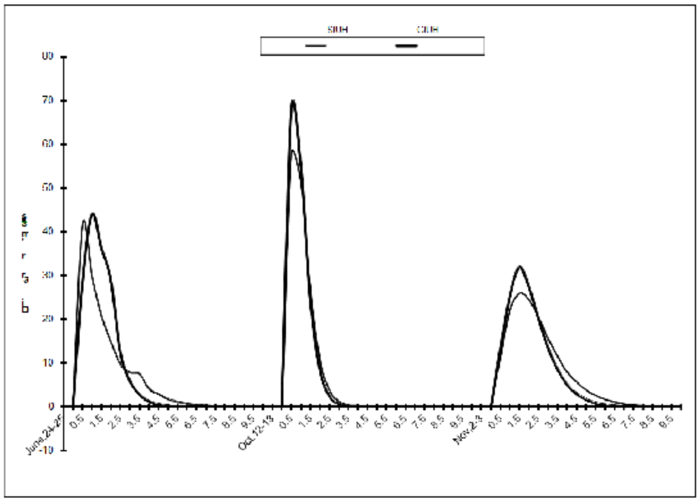

Fig. 1. IUH and GIUH for storm events of June 24-25, Oct 12-13 and Nov 2-3.

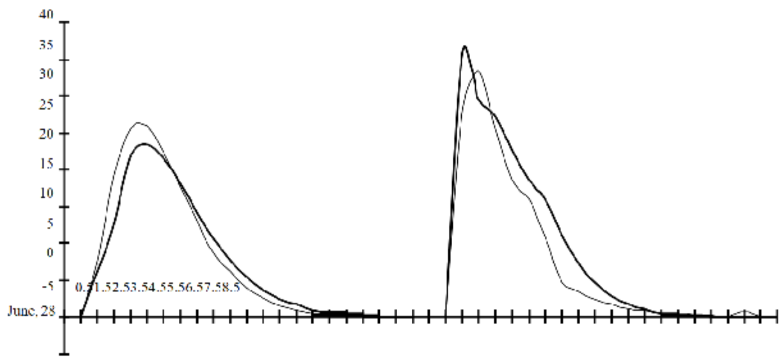

Fig. 2. SIUH and GIUH for storm events of June 28, Aug. 13 and Sept. 15.

Table 4: Ordinates of instantaneous unit hydrograph (IUH).

Time, h	Storm event				
	June, 24-25 (1992)	Oct., 12-13 (1993)	Nov., 2-3 (1993)	June, 28 (1994)	Aug., 6 (1996)
0.0	0	0	0	0	0
0.5	41.57	57.78	11.23	7.28	28.01
1.0	30.01	51.46	22.11	19.11	33.37
1.5	20.83	26.58	25.94	25.62	25.51
2.0	14.91	10.72	24.47	25.93	18.46
2.5	9.79	3.83	20.52	22.48	16.01
3.0	7.92	1.26	15.76	17.7	10.86
3.5	7.54	0.43	11.6	13.01	4.85
4.0	4.2	0.11	7.99	8.7	3.43
4.5	2.96	0.038	5.72	6.15	2.44
5.0	1.83	0.006	3.87	3.98	1.71
5.5	1.21	0.003	2.63	2.56	1.21
6.0	0.79	0.00073	1.72	1.6	0.86
6.5	0.52	0	1.11	0.98	0.61
7.0	0.37	0	0.69	0.58	0.43
7.5	0.22	0	0.45	0.36	0.3
8.0	0.14	0	0.27	0.21	0.22
8.5	0.11	0	0.16	0.12	0.11
9.0	0.062	0	0.1	0.07	0.74
9.5	0.039	0	0.04	0.05	0.052
10.0	0.018	0	0	0	0.032

Table 5: Ordinates of geomorphological instantaneous unit hydrograph (GIUH).

Time, h	Storm event				
	June, 24-25 (1992)	Oct,12-13 (1993)	Nov, 2-3 (1993)	June, 28 (1994)	Aug, 6 (1996)
0.0	0	0	0	0	0
0.5	28.21	68.23	13.4	5.96	35.88
1.0	44.05	54.73	25.46	12.56	29.55
1.5	36.31	24.22	31.99	22.01	27.33
2.0	28.87	8.33	27.36	23.43	22.57
2.5	12.45	2.46	20.23	21.53	18.53
3.0	5.89	0.66	13.63	18.06	15.91
3.5	2.89	0.22	8.63	14.2	11.04
4.0	1.29	0.18	5.2	10.66	7.31
4.5	0.64	0.0093	3.08	7.73	4.66
5.0	0.23	0.0002	1.72	5.44	2.89
5.5	0.1	0	0.94	3.75	1.75
6.0	0.043	0	0.52	2.53	1.05
6.5	0.015	0	0.28	1.69	0.62
7.0	0.0058	0	0.15	1.04	0.35
7.5	0.0002	0	0.076	0.72	0.21
8.0	0.00006	0	0.044	0.46	0.12
8.5	0	0	0.02	0.3	0.06
9.0	0	0	0	0.18	0.03
9.5	0	0	0	0.11	0.0199
10.0	0	0	0	0.072	0.0187

Table 6: Absolute percentage error (APE) of IUH and GIUH of the ordinates at peak.

Sr. No.	Storm events	Peak discharge (m^3/s)		APE (%)
		IUH	GIUH	
1.	June,24-25 (1992)	41.57	44.05	5.97
2.	Oct, 12-13 (1993)	57.78	68.23	18.09
3.	Nov, 2-3 (1993)	25.94	31.99	23.32
4.	June, 28 (1994)	25.93	23.43	-9.64
5.	Aug ,13 (1996)	38.00	28.32	-25.47
6.	Sept. 15, (1996)	34.73	60.36	73.79

CONCLUSIONS

Instantaneous Unit Hydrograph was developed for six storms events of the Khuwatri watershed, which involve the computation of shape parameter (n) and scale parameter (K) based on observed rainfall-runoff database. The values of n and K for the selected storms were computed to be (1.12, 1.22), (2.97, 0.34), (2.82, 0.85), (3.39, 0.74), (1.02, 1.43) and (1.07, 1.57) for storms 1, 2, 3, 4, 5 and 6 respectively. The ordinates of IUH were computed at half hour interval because of small size of watershed. The comparison of GIUH model with storm IUH was performed by determining the Percentage Error (PE) and Absolute Prediction Error (APE) for the peak discharge (q_p) and time to peak (t_p). The Value of APE for q_p and t_p were found 25.35 % and 27.27 %, respectively.

FUTURE SCOPE

Developed model can be applied to other geometrically and morphomertically similar ungauged watersheds to predict the runoff and also for design and construction of various hydrologic structures.

Acknowledgements. Authors acknowledge to College of Agricultural Engineering for providing financial assistance during P.G research work and Damodar Valley Corporation, Hazaribagh (Jharkhand) for providing requisite data, used for development of GIUH model.

Conflict of Interest. None.

REFERENCES

Ashokan, K. (1981). Runoff and sediment yield from Bino sub-watershed of Ramganga catchment. M.Tech Thesis submitted to the department of Soil & Water Conservation Engineering, College of Technology, G.B. Pant Univ. of agric & technology, Pantnagar (Uttranchal).

Bhaskaran, N. R., Parida B. P. and Nayak A. K. (1997). Flood estimation for ungauged catchment using the GIUH. *Journal of Water Resources Research Planning and Management, 7*: 228-238.

Chow, V. T. (1964). Hand book Applied Hydrology. McGraw – Hill Book Company Inc, New York.

Franchini, M. O. Connell, P.E and Todini, E. (1996). An analysis pf the dynamic component of the Geomorphological Instantaneous Unit Hydrograph. *Journal of Hydrology, Amsterdam*.

Kirpich, Z. P. (1940). Time of concentration of small agricultural watersheds. *Civil Eng. (NY), 10* (6): 362

Kumar, J. (1999). Development of Geomorphological Instantaneous Unit Hydrograph. M.Tech Thesis submitted to the Department of Soil & Water Conservation Engineering, College of Technology, G.B. Pant Univ. of agric & technology, Pantnagar (Uttranchal).

Nash, J. E. (1959). Systematic determination of unit hydrograph parameters. *Journal of Geophysical Research, 64*: 111-115.

Rodriguez-Itrube, I., Gonzales, Sanabaria, M. K. Bras, R. L. (1982). A geomorphoclimatic theory of Instantaneous unit hydrograph. *Water Resources Research*, *18*(4): 877-886.

Rodriguez-Itrube, I. and Valdes J. B. (1979). The geomorphologic structure of hydrologic response. *Water Resources Res.*, *15*(6): 1406

Rosso, R. (1984). Nash Model Relation to Horton Order Ratios. Water Resources Research, 20(7), 914-920.

Singh, V. P. (1983). A geomorphic approach to hydrograph synthesis with potential for application to un-gauged watersheds. Tech. Report Louisiana State University, Baton Rouge, LA, 101p

Sorman, A. U. (1995). Estimation of peak discharge using GIUH model in Saudi Arabia. *Journal of Water Resources Planning and Management*, *7*: 287-293.

Subramanyan, K., and Kumar, A. (1990). Runoff modeling of sub watershed of Sahibi catchment based on geomorphology. Indian Council of Agricultural Research, New Delhi, 239 –249.

Troutman, B. M. and Karlinger, M. R. (1985).Unit hydrograpgh approximations using linear flow through topologically ramdam network. Water Resources Res. 21(5), 743-754.

Zhao, T. (1995). Estimation of unit hydrograph by ridge least square method. *Journal of Irrigation and Drainage Engineering*, *121*(3): 253-259.

How to cite this article: Safi Hassan, R. Suresh and S.K. Nirala (2022). Development of Geomorphological Instantaneous Unit Hydrograph (GIUH) Model for a Watershed of Damodar Valley Corporation, Hazaribagh (Jharkhand), India. *Biological Forum – An International Journal*, *14*(1): 908-913.